NOAA Profiler Network and other emerging global profiler networks

Margot H. Ackley[a] and Kenneth S. Gage[b]
[a]Forecast Systems Laboratory and [b]Aeronomy Laboratory,
National Oceanic and Atmospheric Administration

ABSTRACT

The U.S. NOAA Profiler Network operated by the Forecast Systems Laboratory for more than a decade represents the culmination of several decades of research and development of wind profiling Doppler radars. The NOAA Profiler Network is comprised of 35 tropospheric wind profilers (404/449 MHz) mostly located in the central United States. The infrastructure, built over the years for the NOAA Profiler Network has the flexibility and capacity to handle many other profilers in addition to the 35 NOAA Profiler Network systems. With recent advances in computers, networking and communication technologies, real-time profiler data can be acquired from almost anywhere on the globe. Data from remote sites are submitted to quality control and placed onto the Global Telecommunication System. Currently the Forecast Systems Laboratory is receiving data from about 80 sites in the continental U.S., Alaska, Canada, and along the equator west from South America. The data are routed to operational forecast centers where the data are used in a variety of numerical weather prediction models and also distributed to the local forecast offices to tailor model guidance to local conditions. The data are also placed on the Forecast Systems Laboratory web site http://www.profiler.noaa.gov. Here the data may be viewed in many graphical forms and are also available for downloading to a user's site in numeric format.

Keywords: Wind profiling; weather forecasting

1. INTRODUCTION

Wind is perhaps the most important dynamic variable that must be measured to forecast the weather. Conventional means of measuring winds above the surface utilize balloons released simultaneously around the globe. Balloon soundings are made twice daily to support weather analysis and forecasting. In the past twenty years Doppler radar wind profilers have been developed that are capable of continuous measurement of atmospheric winds throughout the troposphere. Frequent wind measurement made possible by the profilers enables the measurement of representative winds with very good resolution. Such measurements have provided a wealth of new information on small-scale atmospheric dynamics and provided a powerful new tool for nowcasting and mesocale forecasting.

The true value of profiler data is just now being recognized. The more profiler data are used, the more their value will be understood and exploited. Moreover, new developments in numerical weather prediction with increased emphasis on mesoscale modeling, especially for air quality and quantitative precipitation forecasting (QPF), promise to increase the value of profiler observations to weather forecasting. Profilers are only one of many new technologies to be developed in the past twenty years. The challenge and opportunity for weather research is to integrate these diverse measurement systems into an efficient system capable of monitoring the atmosphere and providing the optimal data required to support operational forecasting. It is also important to recognize that profilers can do more than measure the wind. Considerable research over the past two decades has demonstrated the contribution profilers can make to the measurement of turbulence and waves as well as precipitation[1,2,3,4].

[a]Margot.H.Ackley@noaa.gov; phone 1 303 497-6791; fax 1 303 497-6014; http://fsl.noaa.gov; NOAA Forecast Systems Laboratory, 325 Broadway R/FS3, Boulder, CO 80305; [b]Kenneth.S.Gage@noaa.gov; phone 1 303 497-3964; fax 1 303 497-5373; http://al.noaa.gov; NOAA Aeronomy Laboratory, 325 Broadway R/AL3, Boulder, CO 80305

2. EARLY HISTORY OF THE DEVELOPMENT OF WIND PROFILING RADAR

The demonstration of the feasibility of measuring the wind in the clear atmosphere using Doppler radar was accomplished over twenty years ago as reported by Gage and Balsley[5] and Hardy and Gage[6]. The work done in the 1970's by NOAA's research laboratories rested on the foundation of decades of earlier research on UHF radio propagation beyond the horizon as well as studies of clear air returns using weather radar and radar studies of the ionosphere. The earliest demonstration of wind profiling was made at VHF with low powered radar utilizing large antennas. The NOAA Profiler Network was motivated by the early success in profiling the winds. Because it was not feasible to operate a large network of profilers at VHF, it was decided that an operational network would need to be operated at UHF. Even at UHF there are many issues concerning the need to protect the frequency band utilized by operational profilers.

The 40 MHz Sunset radar was the first Doppler radar system built exclusively for profiling the lower neutral atmosphere. The construction of the Sunset radar located in the foothills west of Boulder, Colorado was rapidly followed by the construction of the 50 MHz Platteville radar located east of the mountains. The Platteville radar served as a prototype for the powerful VHF radar constructed by the Aeronomy Laboratory (AL) near Poker Flat, Alaska. The Poker Flat radar was an early Mesosphere-Stratosphere-Troposphere (MST) radar that measured winds, waves and turbulence in the lower and middle atmosphere[7]. There is now a small network of MST radars in operation including the MU Radar in Japan and the Indian MST radar located at Gadanki, India.

The first demonstration of an unattended continuously operating wind profiler was accomplished in Platteville, Colorado in 1978 by Ecklund et. al.[8,9]. NOAA's Wave Propagation Laboratory (WPL) [now Environmental Technology Laboratory (ETL)] established the first network[10] of VHF wind profilers in Colorado in the early 1980's. These developments can be viewed as the first steps toward operational wind profiling. Research with this network demonstrated the utility of profilers for routinely obtaining precise wind observations as reported by Strauch and colleagues[11]. Subsequently, WPL created a Profiler Technology Transfer Group that was responsible for the creation of a 30-station network of 404 MHz wind profilers. This network now maintained by the Forecast Systems Laboratory (FSL) is known as the NOAA Profiler Network (NPN) and has been in operation for over ten years.

At the same time that WPL was engaged in the development of the first profiler network to support operational forecasting, the AL was building the first wind profilers to be used in the tropics to support tropical dynamics and climate research[12]. The first profiler data to be sent back in real time from a remote profiler site via satellite was from Christmas Island[13] in 1986. Gage et. al.[14] reported on the impact of this early profiler data on the European Centre for Medium Range Weather Forecasts (ECMWF) and the National Weather Service's National Meteorological Center (NMC; now National Center for Environmental Prediction [NCEP]) analyses. The Christmas Island profiler was the first profiler to be implemented in the Trans-Pacific Profiler Network (TPPN) operated by AL. By the end of 1994 the TPPN was comprised of profilers at six tropical island sites across the Pacific basin from Indonesia to Peru. In addition to VHF wind profilers at Biak, Indonesia; Christmas Island, Republic of Kiribati and Piura, Peru, the network utilized UHF profilers[15,16] to measure lower tropospheric winds.

3. THE NOAA PROFILER NETWORK

The NPN was initiated in 1986 when the United States (U.S.) Government made funds available for the development, deployment and operation of the NPN. The initial network of two prototypes and 30 production systems, operating at an experimental frequency of 404.37 MHz, commenced full operation in May 1992[17]. Several years later three additional systems in Alaska operating at 449 MHz were added to the network. The expanded network is shown in the map in Figure 1. The new frequency of 449 MHz is the designated operational frequency for tropospheric profilers operating within the U.S. When the Alaskan profilers began operation, the U.S. would no longer authorize any more profilers operating at 404 MHz since they could potentially interfere with Search and Rescue Satellites (SARSAT) equipped with instrumentation to detect distress signals from emergency beacons. SARSAT is part of an international program that aids ships, airplanes and people in need of rescue.

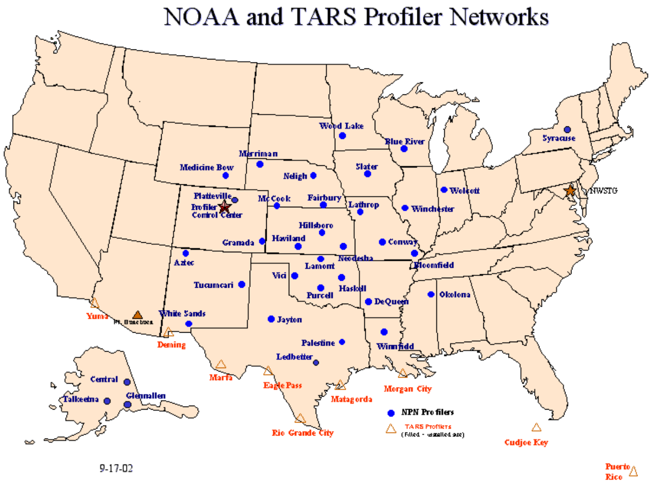

Figure 1. Locations of NOAA Profiler sites and U.S. Air Force Tethered Aerostat Radar System (TARS) sites.

The NPN profilers shown in Figure 2 provide both 6-minute and hourly profiles of the upper-air winds. These profiles consist of 72 levels from 0.5 km to 16.25 km above the profiler site. Since the initial installation of the profiler network, all stations have been equipped with a surface sensor package that measures temperature, humidity, rain accumulation and winds; and a GPS surface-based system which measures total precipitable water above the site[18]. About one-third of the network profilers have Radio Acoustic Sounding System (RASS) that measures profiles of temperature[19]. The NPN operates autonomously and in all weather conditions. The data, along with systems diagnostic information, are sent to the Profiler Control Center (PCC) in Boulder, Colorado. High quality hourly winds and temperatures[20,21,22] are calculated (see Figures 3 and 4) and sent to NPN customers including the U.S. National Weather Service (NWS) and the Global Telecommunication System (GTS). All data are available in near real time on the NPN web site at http://www.profiler.noaa.gov where they can be viewed as graphical displays or text and may be downloaded in numeric format by the customer.

Figure 2. Picture of NPN profiler at Ledbetter, Texas. The 404 MHz co-axial/colinear antenna (winds) is flanked by the equipment shelter (upper left), two of four RASS cones (temperature) and a GPS antenna (water vapor) lower center. The small Yaggi antenna attached to the shelter provides back-up communication through the GOES satellites.

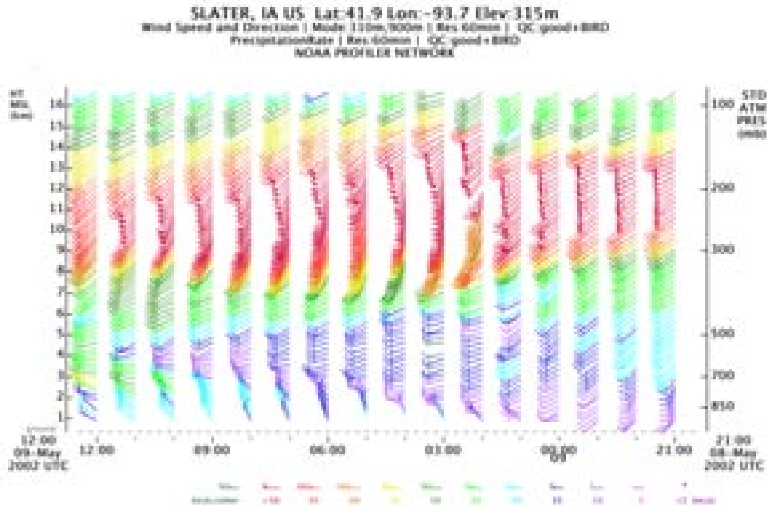

Figure 3. Plot of 16 hourly wind profiles from the Slater, Iowa NPN site. Time goes from right to left. Note the very strong jet stream between 8-12 km.

The NPN data supports NOAA's mission of improving weather products and services, resulting in reduced loss of life and property damage from weather-related events[23,24]. With over 10 years of operation the NPN also supports climate studies. NPN data are used by other U.S. government organizations including those that have military and homeland security missions. The data are used in several NWP models not only in the U.S. but also by the ECMWF and by METEO-France.

After 10 full years of successful operation, the NPN has demonstrated that profiler technology is viable and that networks of profilers can be maintained and operated in an affordable and reliable manner. Over 10 years the NPN has had a consistent data reliability above 90% and more typically 95-97%. Despite a history of successful operation, the NPN will have to be shut down in the future if the critical upgrade of frequency conversion to 449 MHz is not made. The conversion is mandatory to avoid interference with SARSAT equipment that will be added to 60-70 additional satellites.

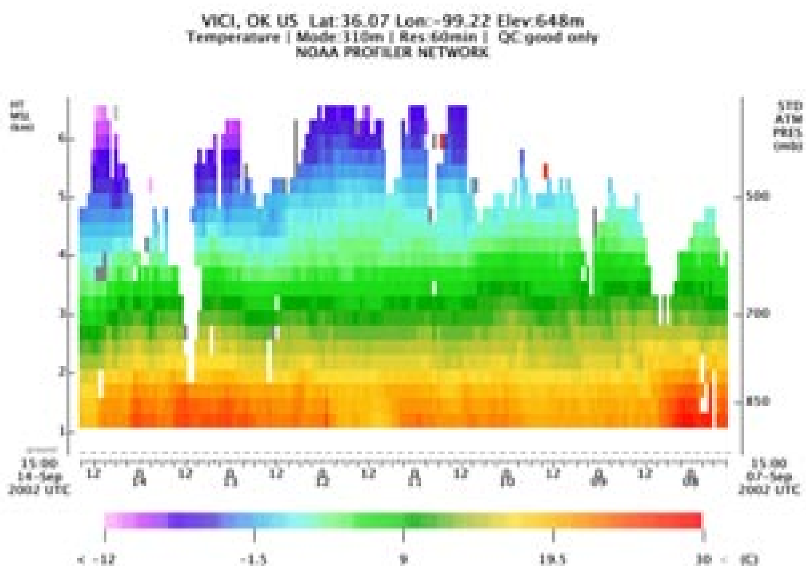

Figure 4. Example of time height cross section of RASS temperature at Vici, Oklahoma, NPN site.

4. COOPERATIVE AGENCY PROFILERS

Over the past years profilers have been used in a wide variety of atmospheric remote sensing applications extending from the boundary layer up through the troposphere and into the lower stratosphere. In addition to the NPN tropospheric profilers there are approximately 80 other profilers operated in the U.S. by other federal, state and local organizations for a variety of purposes including air quality monitoring and weather forecasting. Most of these systems are 1 GHz boundary layer or lower tropospheric profilers. Also included are the TARS quarter-scale 449 MHz profilers owned by the U.S. Air Force (See Figures 1 and 5). Over the past several years FSL has worked closely with the organizations operating these other profilers to receive their data in near real time. These profilers are informally known as Cooperative Agency Profilers (CAP). On acquisition of the data at the NPN's PCC the data are passed through additional quality control before being sent on to the same customers who receive NPN data. These data are also available on the NPN web site (see Figure 6).

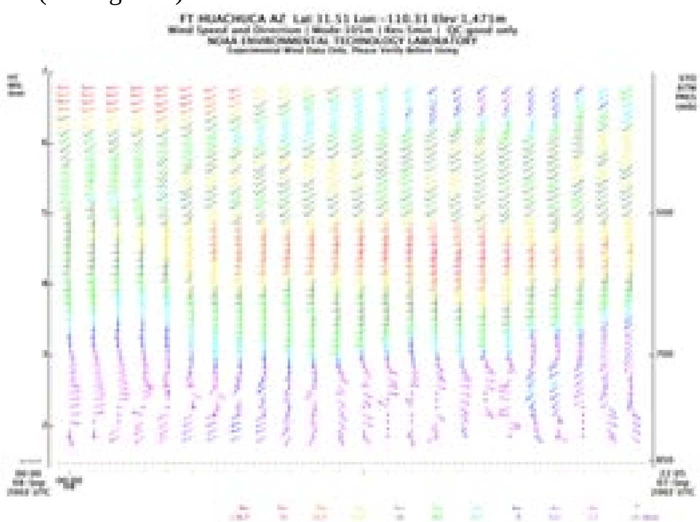

Figure 5. Plot of 24 5-minute wind profiles from TARS quarter-scale 449 MHz Ft. Huachuca, Arizona site. Time goes from right to left. Typical height coverage is 6-8 km.

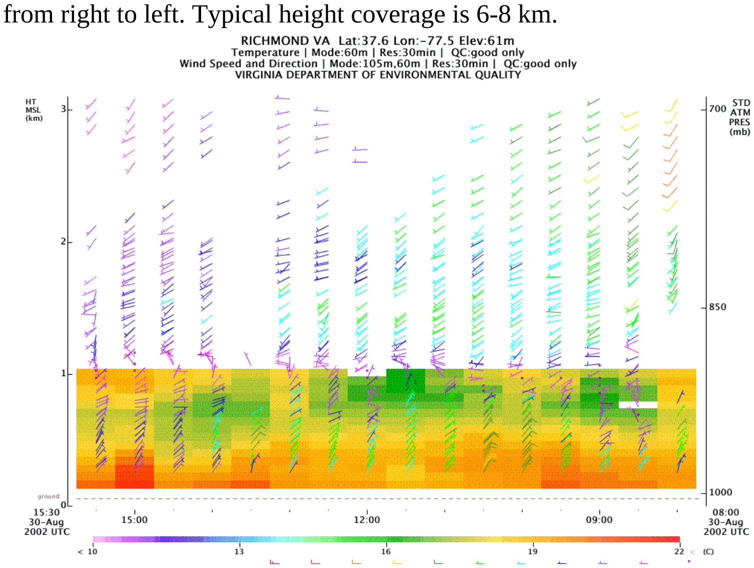

Figure 6. Combined plot of 16 30-minute wind profiles with temperature cross section from a 915 MHz CAP profiler located at Richmond, Virginia. Time goes from right to left. Typical height coverage is 3-5 km for wind and 1-1.5 km for temperature.

5. OTHER GLOBAL NETWORKS

The Japanese Meteorological Agency (JMA) installed a 25-station network of boundary layer profilers operating at 1.3 GHz (Fig. 7). The network operated for about a year in test mode prior to becoming operational in April 2002 with release of data to the GTS. These profilers transmit at a higher power than other lower tropospheric profilers and therefore have higher typical height coverage (6-7 km during moist summers and 3-4 km in dry winters)[25]. JMA has incorporated the profiler data into their 4D-Var assimilation with resulting dramatic improvements in their NWP models for forecasting location and severity of precipitation. Also demonstrated was a significant improvement in the threat scores of the Quantitative Precipitation Forecasts (QPF) for June and September 2001[26].

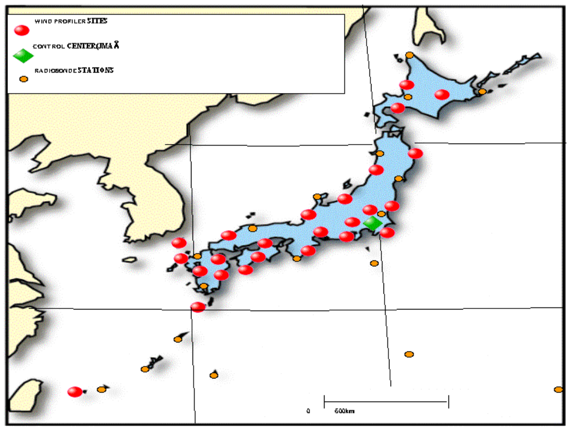

Figure 7. Locations of JMA's 25-station profiler network and 17-station radiosonde network. Also shown is the JMA network control center in Tokyo, Japan.

The United Kingdom (UK) Met Office has deployed a network of 5 profilers (see Fig. 8). One system is a Stratosphere-Troposphere (ST) profiler with height coverage up to 18 km and the others are 1 GHz lower tropospheric profilers with coverage from 3-5 km. The ST profiler has been in operation for ten years and the others commenced operation in early 2000. All Profilers are used by the UK Met Office for nowcasting and forecasting.

Figure 8. Location of UK Met Office 5-station network. For reference purposes, locations of the UK Met Office weather radars are also shown.

In the remainder of Europe there are an additional 20 profilers (see Fig. 9). Collectively all these profilers are part of the COST Wind Initiative for a Network Demonstration in Europe (CWINDE) profiler network. The ECMWF has been conducting studies on the impact of profilers to NWP for several years[27,28]. The value of profiler data is most evident when used in conjunction with a 4D-Var assimilation scheme that takes advantage of the continuous nature of profiler measurements. The NPN profiler data have been used in ECMWF's NWP since the middle of 1999[27]. ECMWF has also been conducting a rigorous assessment of the European profilers and have found that a small but statistically significantly positive forecast impact can result from the use of profilers[28]. These results are similar to studies conducted by FSL using the NPN data[23].

Figure 9. Locations of the profilers in the European continental network that span seven countries.

6. SUMMARY

The last decade has seen wind profiling technology and its ancillary RASS temperature profiling evolve into technologies applicable to a wide variety of research and operational uses. Understanding the complete upper-air wind field is fundamental for all atmospheric related activities. Because upper-air winds from profilers are available at hourly and sub-hourly intervals, the profiler-derived winds more accurately reflect the actual state of the atmosphere compared to traditional systems only reporting information twice per day at 0:00 and 12:00 UTC. Profilers are shown to contribute to NWP in a variety of applications. Their use for subjective forecasting has been demonstrated on numerous occasions in the "tornado alley" of the central U.S. Other key uses will continue to evolve in support of space launch operations, the aviation industry, air quality monitoring, military battlefield operations and other defense applications. It has been demonstrated that a profiler network can be constructed and operated in an affordable way and that the data produced by these networks provide valuable information for a myriad of applications.

7. REFERENCES

1. K.S. Gage and E.E. Gossard, "Recent developments in observation, modelling and understanding atmospheric turbulence and waves", to appear in *Meteorol. Monogr*., 2003.
2. K.S. Gage, C.R. Williams and W.L. Ecklund, "UHF wind profilers: A new tool for diagnosing tropical convective cloud systems", *Bull. Amer. Meteorol. Soc*., **75**, 2289-2294, 1994.
3. K.S. Gage, C.R. Williams and W.L. Ecklund, 1996: "Application of the 915 MHz profiler for diagnosing and classifying tropical precipitating cloud systems", *Meteorol. Atmos. Phys*., **59**, 141-151, 1996.
4. F.M. Ralph, P.J. Neiman, D.W. van de Kamp and D.C. Law, "Using spectral moment data from NOAA's 404-MHz radar wind profilers to observe precipitation", *Bull. Amer. Meteorol. Soc*., **76**, 1717-1740, 1995.
5. K.S. Gage and B.B. Balsley, "Doppler radar probing of the clear atmosphere", *Bull. Amer. Meteorol. Soc*., **59**, 1074-1093, 1978.
6. K. Hardy and K.S. Gage, "The history of radar studies of the clear atmosphere", *Radar in Meteorology*, D. Atlas, ed. Amer. Meteorol. Soc., 130-142, 1990.
7. B.B. Balsley, W.L. Ecklund, D.A. Carter, and P.E. Johnston, "The MST radar at Poker Flat, Alaska", *Radio Sci*., **15**, 213-223, 1980.
8. W.L. Ecklund, D.A. Carter, and B.B. Balsley, "Continuous measurement of upper atmospheric wind and turbulence using a VHF Doppler radar: Preliminary results", *J. Atmos. Terr. Phys*., **41**, 983-994, 1979.
9. B.B. Balsley and K.S. Gage, "On the use of radars for operational wind profiling", *Bull. Amer. Meteorol. Soc*., **63**, 1009-1018, 1982.
10. R.G. Strauch, D.A. Merritt, K.P. Moran, K.B. Earnshaw and D. van de Kamp, "The Colorado wind-profiling network", *J. Atmos. Oceanic Technol*., **1**, 37-49, 1984.
11. R.G. Strauch, B.L. Weber, A.S. Frisch, C.G. Little, D.A. Merritt, K.P. Moran, and D.C. Welsh, "The precision and relative accuracy of profiler wind measurements", *J. Atmos. Oceanic Technol*., **4**, 563-571, 1987.
12. K.S. Gage, B.B. Balsley, W.L. Ecklund, R.F. Woodman, and S.K. Avery, "Wind profiling Doppler radars for tropical atmospheric research", *EOS Trans. AGU*, **71**, 1851-1854, 1990.
13. K.S.Gage, J.R. McAfee, W.L. Ecklund, D.A. Carter, C.R. Williams, P.E. Johnston and A.C. Riddle, "The Christmas Island wind profiler: A prototype VHF wind-profiling radar for the tropics", *J. Atmos. Oceanic Technol*., **11**, 22-31, 1994.
14. K.S. Gage, J.R. McAfee, W.G. Collins, D. Soderman, H. Bottger, A. Radford, and B.B. Balsley, "A comparison of winds observed at Christmas Island (2°N, 157°W) using a wind-profiling Doppler radar with NMC and ECMWF analysis", *Bull. Amer. Meteorol. Soc*., **69**, 1041-1046, 1988.
15. W.L. Ecklund, D.A. Carter, and B.B. Balsley, "A UHF wind profiler for the boundary layer: Brief description and initial results", *J. Atmos. Oceanic Technol*., **5**, 432-441, 1988.
16. D.A. Carter, K.S. Gage, W.L. Ecklund, W.M. Angevine, P.E. Johnston, A.C. Riddle, J. Wilson and C.R. Williams, "Developments in UHF lower tropospheric wind profiling at the NOAA Aeronomy Laboratory", *Radio Sci*., **30**, 977-1001, 1995.
17. D.B. Wuertz, D.E. Wolfe, B.L. Weber and R.B. Chadwick, "NOAA's Wind Profiler Demonstration Network: An overview of applications and impact on research", NOAA Tech. Memo. ERL ETL-249, 29 pp, 1995.
18. D.B. Wolfe, and S.I. Gutman, "Developing an operational, surface-based, GPS, water vapor observing system for NOAA: Network design and initial results", *J. Atmos. Oceanic Technol*., **17**, 426-440, 2000.
19. K.P. Moran, D.B. Wuertz. R.G. Strauch, N.L. Abshire and D.C. Law, "RASS Demonstration on a NOAA Network Wind Profiler", NOAA Tech. Memo. ERL WPL-184, 24 pp, 1990.
20. D.B. Wuertz and B.L. Weber, "Editing Wind Profiler Measurements", NOAA Tech. Memo. ERL WPL-62, 78 pp, 1989.
21. B.L. Weber and D.B. Wuertz, "Quality Control Algorithm for Profiler Measurements of Winds and Temperature", NOAA Tech. Memo. ERL WPL-212, 32 pp, 1991.
22. M.F. Barth, P.A. Miller, D.W. van de Kamp, B.E. Schwartz, R.B. Chadwick, B.L. Weber, and D.B. Wuertz, "An evaluation of real-time quality control techniques applied to subhourly wind profiler data" Preprint Vol., 9th Symposium on Meteorological Observations and Instrumentation, Charlotte, NC, March 27-31. Amer. Meteorol. Soc., 1995.
23. T.W. Schlatter and F.S. Zbar, eds.,"Wind Profiler Assessment Report and Recommendations for Future Use", NOAA, Silver Spring, Maryland, 141 pp, 1994.

24. NOAA, National Weather Service, "Oklahoma/Southern Kansas Tornado Outbreak of May 3, 1999", NWS Service Assessment Report, 53pp, 1999.
25. Y. Ohara, R. Kajihara, Y. Kato and T. Abo, "The wind profiler network of JMA", Proceedings of WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO-2002), Bratislava, Slovak Republic, September 23 –25, 2002.
26. K. Kuizumi, Y. Ishikawa, T. Tsuyuki, and S. Murakami, "Improvement in precipitation forecasts of the JMA mesoscale model with four-dimensional variational data assimilation", Paper presented at The World Weather Research Programme's International Conference on Quantitative Precipitation Forecasting, 2-6 September, 2002, University of Reading, Reading, United Kingdom, 2002.
27. F. Bouttier, "The Use of profiler data at ECMWF", *Meteorol. Zeit*., **10**, 497-510, 2001.
28. E. Andersson and A. Garcia-Mendez, "Assessment of European wind profiler data, in an NWP context", ECMWF Technical Memoranda # 372, European Centre for Medium Range Weather Forecasts, 14pp, 2002.